Description

ENGINE VALVE ACTUATION SYSTEM

Technical Field

[01] The present invention is directed to a system and method for actuating an engine valve and, more particularly, to a variable engine valve actuation system.

Background

[02] The operation of an internal combustion engine such as, for example, a diesel, gasoline, or natural gas engine, may cause the generation of undesirable emissions. These emissions, which may include particulates and oxides of nitrogen (NOx), are generated when fuel is combusted in a combustion chamber of the engine. An exhaust stroke of the engine piston forces exhaust gas, which may include these emissions, from the engine. If no emission reduction measures are in place, these undesirable emissions will eventually be exhausted to the environment.

[03] Research is currently being directed towards decreasing the amount of undesirable emissions that are exhausted to the environment during the operation of the engine. It is expected that improved engine design and improved control over engine operation may lead to a reduction in the generation of undesirable emissions. Many different approaches such as, for example, exhaust gas recirculation, water injection, fuel injection timing, and fuel formulations, have been found to reduce the amount of emissions generated during the operation of the engine. Aftertreatments such as, for example, traps and catalysts, have been found to effectively remove emissions from an exhaust flow. Unfortunately, the implementation of these emission reduction approaches typically results in a decrease in the overall efficiency of the engine.

[04] Additional efforts are being focused on improving engine efficiency to compensate for the efficiency loss due to the emission reduction systems. One

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such approach to improving the engine efficiency involves adjusting the actuation timing of the engine valves. For example, the actuation timing of the intake and exhaust valves may be modified to implement a variation on the typical diesel or Otto cycle, such as the Miller cycle. In a "late intake" type Miller cycle, the intake valves of the engine are held open during a portion of the compression stroke of the piston. Selective implementation of a variation on the conventional actuation timing, such as the Miller cycle, may lead to an improvement in the overall efficiency of the engine.

[05] The engine valves in an internal combustion engine are typically driven by a cam arrangement that is operatively connected to the crankshaft of the engine. The rotation of the crankshaft results in a corresponding rotation of a cam that drives one or more cam followers. The movement of the cam followers results in the actuation of the engine valves. The shape of the cam governs the timing and duration of the valve actuation. As described in U.S. Patent No. 6,237,551 to Macor et al., issued on May 29, 2001, a "late intake" Miller cycle may be implemented in such a cam arrangement by modifying the shape of the cam to overlap the actuation of the intake valve with the start of the compression stroke of the piston.

[06] However, while valve actuation timing adjustments may provide efficiency benefits, these actuation timing adjustments may also result in detrimental engine performance under certain operating conditions. For example, a late intake Miller cycle may be inefficient when the engine is starting, operating under cold conditions, or experiencing a transient condition, such as a sudden increase in engine load. This detrimental engine performance is caused by a decrease in the mass of air flowing through the engine. Especially under cold ambient conditions, the delayed start of compression may lead to cylinder temperatures insufficient to support good combustion and startability.

[07] Thus, to obtain the greatest gains from implementing a variation on conventional valve actuation timing, an engine requires a variable valve actuation system. As noted above, the shape of the driving cam determines the actuation timing of a valve system driven by a cam arrangement. Because the shape of the

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cam is fixed, this type of arrangement is inflexible and may only be changed during the operation of the engine through the use of complex mechanical mechanisms.

[08] The engine valve actuation system and method of the present disclosure solves one or more of the problems set forth above.

Summary of the Invention

[09] In one aspect, the present disclosure is directed to a valve actuation system. The system includes an engine valve moveable between a first position at which the engine valve prevents a flow of fluid relative to the engine valve and a second position at which the fluid flows relative to the engine valve. The system also includes a cam follower operatively connected to the engine valve. A first cam is adapted to engage the cam follower such that the rotation of the first cam acts to move the engine valve from the first position to the second position during a first lift period. A second cam is adapted to engage the cam follower such that a rotation of the second cam acts to affect movement of the engine valve between the first position and the second position during a second lift period. A phase shifting device is operatively connected to the second cam and is adapted to adjust the rotational phase of the second cam relative to the first cam, thereby adjusting the relative timing between the first lift period and the second lift period.

[10] In another aspect, the present disclosure is directed to a method of actuating an engine valve having a first position at which the engine valve prevents a flow of fluid relative to the engine valve and a second position at which the fluid flows relative to the engine valve. A first cam is rotated to engage a cam follower associated with the engine valve to thereby move the engine valve between the first position and the second position during a first lift period. A second cam is rotated to engage the cam follower to thereby affect movement of the engine valve between the first position and the second position during a second lift period. The rotational phase of the second cam is adjusted to thereby adjust the relative timing between the first lift period and the second lift period.

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Brief Description of the Drawings

[11] Fig. 1 is a diagrammatic illustration of an engine valve actuation system in accordance with an exemplary embodiment of the present invention.

[12] Fig. 2 is a pictorial representation of an engine valve actuation system in accordance with an exemplary embodiment of the present invention.

[13] Fig. 3 is a diagrammatic cross sectional illustration of a phase shifting device in accordance with an exemplary embodiment of the present invention.

[14] Fig. 4 is a graph illustrating exemplary valve actuation periods for an engine valve actuation system in accordance with the present invention.

Detailed Description

[15] An exemplary embodiment of an engine 20 is schematically and diagrammatically illustrated in Fig. 1. Engine 20 includes an engine block 22 that defines a plurality of cylinders 23 (one of which is illustrated in Fig. 1). A piston 26 is slidably disposed within cylinder 23 to reciprocate between a top-dead-center position and a bottom-dead-center position.

[16] For the purposes of the present disclosure, engine 20 is described as a four-stroke diesel engine. One skilled in the art will recognize, however, that engine 20 may be any other type of internal combustion engine such as, for example, a gasoline or natural gas engine.

[17] A connecting rod 27 connects piston 26 to an eccentric crankpin 53 of a crankshaft 51. Piston 26 is coupled to crankshaft 51 so that a movement of piston 26 between the top-dead-center position and the bottom-dead-center position results in a rotation of crankshaft 51. Similarly, a rotation of crankshaft 51 will result in a movement of piston 26 between the top-dead-center position and the bottom-dead-center position. In a four-stroke diesel engine, piston 26 will reciprocate between the top-dead-center position and the bottom-dead-center position through an intake stroke, a compression stroke, a combustion stroke, and an exhaust stroke.

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[18] Engine 20 also includes a cylinder head 28. Cylinder head 28 is engaged with engine block 22 to cover cylinder 23 and define a combustion chamber 24. Cylinder head 28 defines an intake passageway 30 that leads from an intake opening 32 in an intake manifold 34 to an intake opening 31 into combustion chamber 24. Intake gases may be directed from intake manifold 34 through intake passageway 30 to combustion chamber 24.

[19] Cylinder head 28 may also define an exhaust passageway (not shown) that leads from combustion chamber 24 to an exhaust manifold (not shown). Exhaust gases from combustion chamber 24 may be directed through the exhaust passageway to the exhaust manifold. These exhaust gases may then be directed from engine 20 and exhausted to the environment.

[20] An intake valve 65 having an intake valve element 68 may be disposed in intake opening 31. Intake valve element 68 is configured to selectively engage a seat 66 in intake opening 31. Intake valve element 68 may be moved between a first position where intake valve element 68 engages seat 66 to prevent a flow of fluid relative to intake opening 31 and a second position where intake valve element 68 is removed from seat 66 to allow a flow of fluid relative to intake opening 31.

[21] Engine 20 also includes a first camshaft 40. First camshaft 40 is operatively engaged with crankshaft 51 of engine 20. First camshaft 40 may be connected with crankshaft 51 in any manner readily apparent to one skilled in the art where a rotation of crankshaft 51 will result in a corresponding rotation of first camshaft 40. For example, as seen in Fig. 2, first camshaft 40 may be connected to crankshaft 51 through a gear train that reduces the rotational speed of first camshaft 40 to approximately one half of the rotational speed of crankshaft 51.

[22] As seen in Fig. 1, a first cam 42 may be disposed on first camshaft 40 to rotate with first camshaft 40. First cam 42 may include a cam lobe 44 having for example, an elliptical surface. As will be explained in greater detail below, the shape of cam lobe 44 on first cam 42 will determine, at least in part, the actuation timing of intake valve element 68. One skilled in the art will recognize that first cam 42 may include an additional cam lobe and/or the cam lobe may

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have a different configuration depending upon the desired intake valve actuation timing.

[23] Engine 20 also includes a series of valve actuation assemblies 36 (one of which is illustrated in Fig. 1). One valve actuation assembly 36 may be provided to move intake valve element 68 between the first and second positions. Another valve actuation assembly 36 may be provided to move an exhaust valve element (not shown) between the first and second positions.

[24] It should be noted that each cylinder head 28 may include multiple intake openings 31 and exhaust openings (not shown). Each such opening will have an associated intake valve element 68 or exhaust valve element (not shown). Engine 20 may include two valve actuation assemblies 36 for each cylinder 23. The first valve actuation assembly 36 may be configured to actuate each of the intake valve elements 68 for each cylinder 23, and the second valve actuation assembly 36 may be configured to actuate each of the exhaust valve elements. Alternatively, engine 20 may include a separate valve actuation assembly to actuate each intake valve element 68 and each exhaust valve element.

[25] Each valve actuation assembly 36 includes a rocker arm 64 having a first end 76, a second end 78, and a pivot point 77. First end 76 of rocker arm 64 is operatively engaged with a push rod 48. Second end 78 of rocker arm 64 is operatively engaged with intake valve element 68 through a valve stem 70. Rotation of rocker arm 64 about pivot point 77 causes intake valve 65 to move from the first position to the second position.

[26] A cam follower 50 may be disposed between push rod 48 and first cam 42. Cam follower 50 may include a first end 57 and a second end 58. Cam follower 50 may be adapted to pivot about a axis 59.

[27] First end 57 of cam follower 50 is adapted to engage the surface of cam lobe 44 as first cam 42 rotates. The rotation of first cam 42 causes cam follower 50 to pivot about axis 59. The pivoting motion of cam follower 50 moves push rod 48 to thereby produce a reciprocating motion of push rod 48 and a

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pivoting motion of rocker arm 64 about pivot point 77. In this manner, rotation of first cam 42 acts to lift, or open, intake valve 65.

[28] Valve actuation assembly 36 may also include a valve spring 72. Valve spring 72 may act on a valve stem 70 through a retainer 74. Valve spring 72 may act to move intake valve element 68 relative to cylinder head 28. In the illustrated embodiment, valve spring 72 acts to bias intake valve element 68 into the first position, where intake valve element 68 engages seat 66 to prevent a flow of fluid relative to intake opening 31. Thus, the rotation of first cam 42 will cause intake valve 65 to move from the first position and valve spring 72 will return intake valve 65 to the first position. Cam lobe 44 of first cam 42 may be adapted to actuate intake valve 65 for a first lift period 92.

[29] A second cam 52 may be operatively engaged with intake valve 65. Second cam may include a cam lobe 54 having, for example, an elliptical surface. Cam lobe 54 of second cam 52 may be adapted to engage second end 58 of cam follower 50.

[30] Second cam 52 may be mounted on a rotatable second camshaft 56. A rotation of second cam 52 causes cam follower 50 to pivot about axis 59 producing a reciprocating motion of push rod 48. The reciprocating motion of push rod 48 causes a pivoting motion of rocker arm 64 about pivot point 77, thereby moving intake valve 65 from the first position to the second position. Second cam 52 and valve spring 72 may be adapted to actuate intake valve 65 for a second lift period 98 (referring to Fig. 4).

[31] Second cam 52 may be adapted to affect the movement of intake valve 65. For example, second cam 52 may act to open intake valve 65, delay the movement of intake valve 65, or retard the movement of intake valve 65. As will be explained in greater detail below, under certain circumstances, the rotational phase of second cam 52 may be adjusted so that second cam 52 does not alter the movement of intake valve 65.

[32] It should be noted that the second lift period 98 (referring to Fig. 4) may overlap with the first lift period 92 (referring to Fig. 4). In other words, first cam 42 may have already lifted intake valve 65 from the first position before cam

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lobe 54 of second cam 52 rotates to engage cam follower 50. In this situation, second cam 52 may not contact cam follower 50 as first cam 42 may have already caused cam follower 50 to pivot and cause rocker arm 64 to lift intake valve 65.

[33] As shown in Fig. 2, a phase shifting device 82 may be adapted to act on second camshaft 56. Phase shifting device 82 may be operable to adjust the rotational phase of second camshaft 56 and/or second cam 52 relative to first camshaft 40. Phase shifting device 82 may advance or retard the rotational phase of second camshaft 56 and/or second cam 52 relative to first camshaft 40. Once the phase shift is complete, first and second camshafts 40 and 56 will continue to rotate at the same speed, e.g. approximately one-half the speed of crankshaft 51. However, the position of cam lobe 54 of second cam 52 will have shifted relative to the position of cam lobe 44 of first cam 42.

[34] For example, Fig. 4 illustrates a graph 90 depicting a first lift period 92 such as may be initiated by first cam 42 and a second lift period 98 such as may be initiated by second cam 52. First lift period 92 includes a start 94 and an end 96. Second lift period includes a start 100 and an end 102. In an exemplary base phasing position, first and second lift periods 92 and 98 will overlap. When the first and second lift periods 92 and 98 overlap, the lifting of intake valve 65 may be controlled entirely by first cam 42 so that intake valve 65 returns to the first position at the end 96 of the first lift period 92.

[35] Phase shifting device 82 may be operated to delay the rotational phase of second camshaft 56 and/or second cam 52 with respect to first camshaft 40. A delayed second lift period 98′ is also illustrated in Fig. 4. As shown, delayed second lift period 98′ has a start 100′ and an end 102′. The phase change delays the engagement of second cam 52 with cam follower 50 (referring to Fig. 1). Thus, second cam 52 will delay the closing of intake valve 65 to end 102′ of delayed second lift period 98′. Control over the movement of intake valve 65 will be transferred from first cam 42 to second cam 52 at a transfer point 104. Thus, by changing the rotational phase of second cam 52 relative to first cam 42, the actuation period of intake valve 65 may be varied.

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[36] Phase shifting devices capable of shifting the phase of a cam are well known in the art. One skilled in the art will recognize that phase shifting device 82 may include any means for changing the rotational phase of a shaft or cam such as, for example, a camshaft shift, a cam lobe shift, a hydraulic device, an indexing motor, or a mechanical or hydraulic cam shifting mechanism. In addition, phase shifting device 82 may include a synchronous motor, an electro-hydraulic device having a helical spline, a mechanical drive with relative angular position based phasing, or any other similar synchronous phasing device.

[37] As shown in Fig. 3, phase shifting device 82 is an electro-hydraulic device having a helical spline 83. The helical spline is engaged to internal gear teeth 84 of a drive gear 85 operably connected to the crankshaft 51 and adapted to drive the rotation of second camshaft 56. The helical spline is also operably engaged to the second camshaft 56, thereby transferring torque from the drive gear 85 to the second camshaft 56.

[38] A hydraulic piston 86 is adapted to apply force to the helical spline 83 causing the helical spline 83 to rotate with respect to the drive gear 85. The rotation of the helical spline 83 results in a corresponding rotation of the second camshaft 56, thereby affecting phase shifting. When the hydraulic piston 86 extends towards the second camshaft 56, the rotation of the helical spline 83 and second camshaft 56 results in advanced timing. When the hydraulic piston 86 retracts, the rotation of the helical spline 83 and second camshaft 56 results in a retarded timing. Alternatively, when the hydraulic piston 86 extends towards the second camshaft 56, the rotation of the helical spline 83 and second camshaft 56 may result in retarded timing. Likewise, when the hydraulic piston 86 retracts, the rotation of the helical spline 83 and second camshaft 56 may result in advanced timing.

[39] An impact-absorbing device (not shown) may be used to decrease the impact on cam follower 50 when first cam 42 and second cam 52 engage cam follower 50. For example, the impact-absorbing device may be a cam that acts to decelerate the rocker arm 64 or intake valve 65 just prior to transfer point 104.

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Alternatively, the impact absorbing device may include a travel limited hydraulic lifter or a spring/damper combination.

[40] In addition, an adjustment device (not shown) may be operatively associated with cam follower 50 and/or the impact-absorbing device. The adjustment device may be adapted to adjust the position of cam follower 50 relative to first cam 42 and second cam 52. The adjustment device may be used to compensate for manufacturing tolerances and/or changes in the size of components due to temperature changes. The adjustment device may include any means for changing the position of cam follower 50 relative to first cam 42 and second cam 52. For example, the adjustment device may include threads, nuts, springs, detents, or any other similar position adjusting mechanism.

Industrial Applicability

[41] The operation of engine 20 will cause a rotation of crankshaft 51, which will cause corresponding rotations of first and second camshafts 40 and 56. The rotation of first camshaft 40 and first cam 42 towards cam follower 50 causes a reciprocal motion of push rod 48 that pivots rocker arm 64 to start first lift period 92 (referring to Fig. 4) of intake valve 65. First lift period 92 may be coordinated with the movement of piston 26. For example, start 94 of first lift period 92 may coincide with the movement of piston 26 from a top-dead-center position towards a bottom-dead-center position in an intake stroke. The movement of intake valve 65 from the first position to the second position allows a flow of fluid to enter combustion chamber 24.

[42] The rotation of second camshaft 56 will rotate second cam 52 and cam lobe 54 towards cam follower 50 causing a reciprocal motion of push rod 48 and associated second lift period 98 (referring to Fig. 4). However, when second cam 52 is in a base phasing position, second lift period 98 will overlap with first lift period 92. In other words, first cam 42 has already moved intake valve 65 from the first position to the second position and, therefore, cam lobe 54 may not actually engage cam follower 50 or otherwise impact the lifting movement of intake valve 65.

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[43] As first cam 42 and cam lobe 44 continue to rotate, valve spring 72 will act to return intake valve 65 to the first position and end first lift period 92. End 96 of first lift period 92 may, for example, be timed to coincide with the movement of piston 26 to the bottom-dead-center position at the end of the intake stroke. The return of intake valve 65 to the first position prevents additional fluid from flowing into combustion chamber 24.

[44] Phase shifting device 82 may be operated to change the rotational phase of second cam 52 relative to first cam 42. For example, phase shifting device 82 may delay the rotational phase of second cam 52 relative to first cam 42. When the rotational phase of second cam 52 is delayed, the second lift period 98 will be delayed relative to the first lift period 92.

[45] A delay in the rotational phase of second cam 52 may delay the return of intake valve 65 to the first position. In a delayed phase position, cam lobe 54 of second cam 52 will rotate into a position to engage cam follower 50 at a later time, relative to the motion of first cam 42. This may result in cam lobe 54 engaging cam follower 50 at transfer point 104 (referring to Fig. 4). Cam lobe 54 will therefore prevent intake valve 65 from returning to the first position until end 102′ of delayed second lift period 98′. End 102′ of delayed second lift period 98′ may be timed to coincide with a certain movement of piston 26. For example, second lift period 98′ may be timed to end after piston 26 moves through a first portion of a compression stroke, such as in a “late-intake” type Miller cycle.

[46] The rotational phase of second cam 52 may be adjusted incrementally between the base phasing position and a fully delayed phasing position. An incremental change in the phasing position of second cam 52 will change the time at which intake valve 65 returns to the first position relative to the motion of piston 26. For example, an increased delay in the phasing position of second cam 52 may cause intake valve 65 to return to the first position after piston 26 has completed a greater portion of an intake stroke. A decreased delay in the phasing position of second cam 52 may cause intake valve 65 to return to the first position after piston 26 has completed a lesser portion of an intake stroke.

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Thus, by changing the rotational phase of second cam 52, the actuation timing of intake valve 65 may be varied.

[47] The rotational phase of second cam 52 is accomplished by directing pressurized fluid to piston 86 forcing helical spline 83 to move axially with respect to gear 85. The helical nature of the helical spline 83 causes a rotating motion as the helical spline is forced to move axially with respect to the gear 85. Camshaft 51 being connected to the helical spline 83 is forced through a corresponding rotation, thereby affecting phase shifting of second cam 52. When the hydraulic piston 86 extends towards the second camshaft 56, the rotation of the helical spline 83 and second camshaft 56 results in advanced timing. When the hydraulic piston 86 retracts, the rotation of the helical spline 83 and second camshaft 56 results in a retarded timing.

[48] As will be apparent from the foregoing description, the disclosed system and method provide for the varying of the actuation of an engine valve of an engine. By shifting the rotational phase of a second cam relative to a first cam, the actuation timing of an engine valve, such as an intake valve or an exhaust valve, may be adjusted. The rotational phase of the second cam may be controlled to implement a variation on conventional valve timing such as, for example, a late-intake type Miller cycle.

[49] It will be apparent to those skilled in the art that various modifications and variations can be made in the engine valve actuation system of the present invention without departing from the scope of the invention. Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope of the invention being indicated by the following claims and their equivalents.

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